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Review of spatial-database system usability:

Recommendations for the ADDNS Project

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Defence R&D Canada
Technical Report
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Abstract

Geospatial information systems (GIS) are a relatively new technology. The key GIS technology strengths are its capabilities to store attributes of various spatial features, provide spatial-analysis functionality and offer multiple-perspective, two-dimensional (2D) and three-dimensional (3D) visualizations. This report presents an overview of the basic concepts of GIS and spatial databases, provides an analytical usability evaluation and critically analyses different spatial-database applications for different fields, with special emphasis on defence-related applications. We provide a comprehensive spatial-database evaluation methodology. Basic and advanced functions for GIS operations are analysed, with a focus on selected major GIS products and selected common database systems. Optimal system-requirement recommendations for spatial-database design are provided, with particular attention paid to the needs of the Advanced Deployable Day and Night Simulation (ADDNS) project. This report provides a detailed overview of spatial-database technologies to assist decision-makers with selecting the best system for a particular task.

Résumé

Les systèmes d'information géographique (SIG) constituent une technologie relativement nouvelle. Les atouts technologiques des SIG sont leur capacité à stocker des attributs de diverses entités spatiales, leurs fonctionnalités d'analyse spatiale et leurs multiples possibilités de visualisation en perspective, en deux dimensions (2D) et en trois dimensions (3D). Ce rapport présente un aperçu des concepts fondamentaux des SIG et des bases de données spatiales tout en offrant une évaluation de leur utilité pour l'analyse; on y présente en outre des analyses critiques de différentes applications des bases de données spatiales dans différents domaines en insistant en particulier sur les applications reliées à la défense. Nous offrons une méthodologie complète d'évaluation des bases de données spatiales. Les fonctions de base et évoluées des SIG sont analysées d'après les principaux produits de SIG et des systèmes communs choisis de bases de données. Des recommandations sont formulées quant aux exigences systèmes optimales pour la conception de bases de données en prêtant une attention particulière aux exigences du projet de la simulation déployable avancée pour la vision de jour et de nuit (ADDNS). Le présent rapport fournit un aperçu détaillé des technologies des bases de données spatiales comme aides à la prise de décisions pour le choix du système le mieux adapté à une tâche particulière.

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Executive summary

Review of spatial-database system usability: Recommendations for the ADDNS Project

Rifaat M. Abdalla; Keith K. Niall; DRDC Toronto TR 2007-141; Defence R&D Canada – Toronto; December 2007.

Introduction: Geospatial information technology provides the advanced tools used by many decision-makers. This report provides technical information to decision-makers who lack a practical GIS background. The core objective of this report is to review the fundamental concepts of geographic information systems (GIS) and spatial databases, and suggest an assessment mechanism for various applications. The research methodology adopted in this report is based on a critical review of published GIS literature. This study includes detailed functionality analysis of selected products and applications and provides a basic scientific background supported by technical analysis of user and system requirements.

This report contains six main sections.

The Introduction section provides a brief overview.

The Background information section provides a detailed overview of GIS technology, GIS terms and GIS data structure. This section includes a brief discussion of the object-class and field-class data models. The Background information section also explains the principles of designing spatial databases followed by the theoretical concepts associated with spatial databases and database types. Detailed expansions on both the relational and the object-oriented database model are provided.

The Functionality analysis of major GIS products section is an analysis of three major GIS products, providing technical reviews of ERDAS IMAGINE®, Geomatica® and ESRI® ArcGIS®. The second half of this section reviews four major database systems: Oracle® Spatial, Microsoft® SQL Server™, IBM® Informix, and ESRI® ArcSDE.

The Database system and design requirements section provides a technical evaluation of the system and design requirements for implementing an advanced spatial-database system, integrating geospatial database components and providing advanced perspective visualization. Special emphasis is given to common considerations in system-design requirements, user requirements and operational constraints.

The Applications review section provides a critical review of various applications currently using geospatial databases. Because the processes of developing spatial databases are similar; this review is not limited to defence-related activities.

The Conclusions and recommendations section is the final main section in this report.

Sommaire

Review of spatial-database system usability: Recommendations for the ADDNS Project:

Rifaat M. Abdalla; Keith K. Niall; DRDC Toronto TR 2007-141; R & D pour la défense Canada – Toronto; Décembre 2007.

Introduction: La technologie de l'information géospatiale fournit des outils évolués à un grand nombre de décideurs. Dans ce rapport on offre de l'information technique aux décideurs qui n'ont pas une connaissance pratique des SIG. Le principal objectif est de fournir un aperçu des concepts fondamentaux des systèmes d'information géographique (SIG) et des bases de données spatiales tout en proposant un mécanisme d'évaluation pour diverses applications. La méthodologie de recherche adoptée pour la présente étude est fondée sur un examen critique de la documentation publiée sur les SIG. L'étude fournit une analyse de fonctionnalité détaillée de produits et d'applications choisis ainsi qu'un contexte scientifique s'appuyant sur une analyse technique des besoins des utilisateurs et des exigences systèmes.

Ce rapport comporte six sections principales.

L'introduction fournit un bref aperçu.

La section sur l'information contextuelle offre un aperçu détaillé de la technologie des SIG, de la terminologie et de la structure de données utilisée par les SIG. Elle comporte une brève discussion des modèles de données basés sur les classes d'objets et sur les classes de champs. La section sur l'information contextuelle explique en outre les principes de conception des bases de données spatiales ainsi que les concepts théoriques associés aux bases de données spatiales et aux types de bases de données. Des explications détaillées des modèles de base de données relationnelles et orientées objet sont fournies.

La section sur l'analyse de fonctionnalité des principaux SIG comporte des examens techniques du ERDAS IMAGINE®, du Geomatica® et de l'ArcGIS® d'ESRI®. Dans la deuxième partie de cette section on examine quatre des principaux systèmes de bases de données : Oracle® Spatial, SQL Server™ de Microsoft®, Informix d'IBM® et ArcSDE d'ESRI®.

La section sur les exigences de conception et les exigences systèmes des bases de données fournit une évaluation technique de ces éléments en vue de l'implantation d'un système évolué de base de données spatiales intégrant des composantes de base de données géospatiales et offrant une capacité évoluée de vue perspective. Une emphase particulière est accordée aux considérations courantes en matière d'exigences de la conception de systèmes, de besoins des utilisateurs et de contraintes opérationnelles.

La section sur l'examen des applications jette un regard critique sur diverses applications courantes utilisant des bases de données géospatiales. Puisque les processus d'élaboration des bases de données spatiales sont les mêmes dans tous les domaines, cet examen ne se limite pas aux activités dans le domaine de la défense.

Une section présentant des conclusions et des recommandations termine le rapport.

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1 Introduction

When dealing with information technology (IT) infrastructure, today's decision-makers who lack a geospatial information system (GIS) background face critical challenges, as noted by ESRI® [1]. Decisions involving spatial components require detailed information, system-structure background and up-to-date IT knowledge. A broad range of management and decision-making processes have been linked to the requirement for effective technological solutions. Due to rapid developments in IT, both computer storage and processing capabilities are no longer issues. A new challenge has emerged; the rapid technological advancement of information infrastructure. The advancements in databases, visualization tools and modeling processors causes continuously aging IT infrastructure.

GIS use spatial databases to provide advanced integrated systems for virtual-reality (VR) simulation. Spatial databases and GIS provide the computerized tools for capturing, managing, accessing, analysing and visualizing geographic and related information concerning all aspects of defence. GIS uses spatial databases to provide powerful tools for real-world visualization and simulation. These tools provide the mechanism to allow data sharing among all the specialists and groups involved in various aspects of defence-related activities, optimizing coordination and leveraging data and information. This enables virtual simulation training in synthetic environments based on common scenarios.

Defence applications using GIS and spatial databases are becoming increasingly important for three key reasons. First, the use of GIS in database-centric simulation systems synthesizes real-world scenarios, avoiding significant effort and cost. Next, GIS enables unique database-updating capabilities and management of multiple scenarios. Finally, GIS is the critical technology in the integration and exploitation of remotely-sensed data and digitally-captured features in the form of vector spatial information. GIS technology offers ease and efficiency in integrating different systems such as computers, satellites, global positioning systems (GPS) and field devices. GIS technology also integrates different data types, including real-time satellite data, weather information and hydrographic information sources. GIS technology combines various applications, including environmental, health and defence applications. This broad range of applications makes GIS one of the fastest growing technologies in the world, with a wide range of users and applications.

This report introduces non-technical decision-makers to GIS as a useful tool to aid them in their decision making process.

2 Background information

GIS technology has three key capabilities: querying and obtaining information, analytical modeling and visualization of models, and analysis of results. These capabilities depend upon the spatial databases at the core of the GIS. This section provides a broad overview of basic GIS background information, with a closer look at spatial databases.

A GIS is also a computer-based system designed to capture, manage, manipulate, analyse, model and display spatially-referenced data, as described by Aronoff [2]. Today, GIS are widely used in many government, business and private activities, falling into the three major categories outlined by Longley et al. [3]:

- socio-economic applications: urban and regional planning, cadastral registration, archaeology, natural resources, and market analysis
- environmental applications: forestry, fire and epidemic management
- management applications: pipeline network design, other utilities, such as electricity and telephones, and real-time navigation for vessels, planes and cars

The role of GIS in these applications is to provide users and decision-makers with effective tools for solving the complex and usually semi-structured problems based on their spatial dimension, while providing an adequate level of performance. GIS support should include an operating system, a graphic product for input and output, routines supplied by the GIS programming language and numerous other software products, as described by Goodchild [4]. The database support for GIS is the backbone of successful applications.

2.1 GIS and data

GIS technology is relatively new. The wide range of GIS capabilities and functionalities make it difficult for the geomatics community and the GIS users' community to develop a concrete definition for GIS. GIS technology is an interdisciplinary science; some researchers use GIS technology for particular applications, while others use it for database management or to integrate and spatially enable the functionality of their existing software. From this perspective, GIS can be seen as a technology, a system, an application or an infrastructure. In a narrower context, GIS is defined as a computer-based system for the input, storage, manipulation, analysis, retrieval and display of spatial information. GIS is also defined as the science behind the technology used for remote sensing (RS), and GPS. GIS technology is unique because it integrates spatial and non-spatial data in a single database.

Data in GIS are divided into two categories: spatial and non-spatial data. Spatial data are the elements that have ground coordinates and can be stored in the GIS database. These elements correspond to a uniquely-defined location on the Earth's surface. Spatial data have also been defined by Pequet and Marble [5] as any data concerning phenomenon that are areally distributed. Spatial data can be both thematic, describing the character of the real-world feature data reference; or temporal, providing a record of when the data were collected. Non-spatial data are

attributes associated with a parcel feature on a GIS database. This tabular information includes number, area and land class.

GIS exploit spatial data to provide the user with sustainable applications that can be updated, manipulated and analysed. Moreover, GIS provide us with the ability to analyse relationships and to visualize these relationships from a wide range of perspectives in two, three and four dimensions.

2.2 Data models and feature representation

The process of GIS data abstraction starts with identifying a real-world spatial feature, then representing the conceptual model of this selected feature using an appropriate data model and finally selecting the appropriate spatial data structure (see Annex A). In GIS, data models are mainly classified into two major categories: vector data models and raster data models.

2.2.1 Spatial data structure

2.2.1.1 Vector data

Vector data structure is defined by Korte [6] as data in the form of an array with one dimension. Vector data also refers to a directed line segment with a magnitude commonly represented by the coordinate for a pair of end points. There are three entities in the vector data model:

- Points are single locations in two dimensional (2D) or three dimensional (3D) space. For example a point can represent a city on a map or an intersection point of two streets in a GIS database.
- Lines can be isolated, within a tree-structure or as elements of a network structure, within the network. For example, a line can represent a road or a river in a GIS database.
- Polygons can be isolated, adjacent or nested. Polygons can represent a building or provincial boundaries in a GIS database.

2.2.1.2 Raster data

Raster data structure represents geographical space by dividing the space into a series of units known as pixels. Each pixel is limited and defined by an equal amount of earth's surface. From a GIS perspective, the raster data model is considered a simple data model, largely because the modeling and analysis tasks are easily processed within this model. However, this model's disadvantage is the spatial inaccuracies very often associated with the analysis operations. The level of inaccuracies depends on the scale and level of detail (LOD) required.

2.2.1.3 Digital-elevation data

There is a third data structure that can be linked to either the vector or the raster data model: digital elevation data. This type of data is 3D. The triangulated irregular network (TIN) data model is one example of digital elevation data. The TIN model is an alternative to the raster and

vector data models for representing continuous surfaces. Surface models are generated efficiently, enabling analysis and display of terrain and other types of surfaces. The TIN model is also flexible because this model's data can easily be converted into raster data or vector contour lines.

2.2.2 Spatial data models

From a GIS perspective, spatial data can be classified into two models: the field-class data model and the object-class data model.

2.2.2.1 Field-class data model

In the field-class data model, maps are conceptualized as series of layers or fields, with one type of feature represented by a single layer. Variables in a field-class data model are mapped over the area covered by the database and have a unique value at every point within the layer.

2.2.2.2 Object-class data model

The object-class data model views the world as a set of individual objects and therefore represents real-world phenomena in greater detail than the field-class data model. This makes the object-class data model an accurate data model more representative of reality. In the object-class data model, space between objects may be empty or occupied by one or more objects. Objects can overlap, unlike in the field-class data model.

2.3 Spatial-database design principles

Many geomatics researchers have discussed the basic principles of designing spatial databases. Nielsen [7] provided five major steps for the pre-design phase of geographic databases:

1. providing a comprehensive framework of the database

2. allowing the database to be viewed in its entirety so interaction and linkages between elements can be defined and evaluated

3. permitting identification of potential bottlenecks and problem areas so design alternatives can be considered

4. identifying the essential and correct data to be included in the database and filtering out irrelevant data

5. defining update procedures so newer data can be incorporated in the future

The National Center for Geographic Information and Analysis in the United States suggested that the design of the GIS database include the three major elements that follow, see Goodchild and Kemp [8].

2.3.1 Conceptual design

Conceptual design of spatial databases involves determining the application requirements and specifying the end user of the database. This phase outlines the end-user goals. Conceptual design involves five major steps:

1. specifying the use of spatial database
2. specifying the LOD
3. specifying the spatial elements of GIS databases
4. specifying the type of non-spatial elements to be exploited in the database, including labels, text and attributes
5. other considerations, including availability and source of spatial and non-spatial data, age of data and type of coordinate system; however, these considerations do not seem to be an issue given the advances in GIS data capture as well as software and hardware capabilities.

2.3.2 Logical design

The second stage of designing spatial database is identifying the type of database system and GIS products appropriate to the particular application. The coordinate system for databases is one important aspect to be considered in the logical design of spatial databases. Database tolerances specify the acceptable error-level associated with each spatial element.

2.3.3 Physical design

The physical database design refers to the process of identifying the hardware and software characteristics for particular applications. In this stage, consideration of basic system components is important. These components include:

- file structure
- data formats
- memory
- disk space
- processing speed
- graphic cards

The disk space and memory requirements are no longer a major concern for GIS database designers; this is because of the recent developments in GIS software technology. The three major issues to be addressed, in particular with the Advanced Deployable Day Night Simulation (ADDNS) project, are:

- the load of the database, i.e., its ability to retrieve information in a timely fashion

- the volume of data estimates in each spatial element
- the access speed requirements for managing large satellite imagery (rather than the processing time involved)

2.4 Database concepts

Bédard [9] has defined a spatial database as "any set of data describing the semantic and spatial properties of real-world phenomena, including temporal properties." With this concept in mind, such databases can be implemented in GIS with a database management system (DBMS). These databases can be used in spatial database engines (SDEs) and accessed through an application program interface (API). Spatial databases can use standard file structures with a GIS viewer to visualize, edit and analyse spatial data.

2.5 Database types

In the past, databases were developed in the form of paper, flat-file databases. The relational database model is one of the advanced database models that came into existence in the 1980's. The object-oriented database model appeared in the 1990's. These two major database models are discussed briefly in the following two sections.

2.5.1 Relational database model

The relational database model, an extremely popular model, solves many of the problems encountered in other models, such as linking multiple records and assigning a unique identifier for each field. The relational database model is different from other database models, including the object-oriented model, because in this model all of the databases and their components are equal. Data can be stored in any number of separate databases and these databases are then connected by a key field. All of the databases can be used to hold different types of data. This type of database model makes it easy to search for and extract data from the databases. Figure 1 illustrates spatial databases' components as modified from ESRI [10].

2.5.2 Object-oriented database model

Object-oriented databases can store photos, sounds, videos and graphics. This a very advanced database model that can integrate multiple data formats. Shekar and Chawla [11] identified the base model of spatial databases as a model that focuses abstract spatial information into distinct, identifiable and relevant items, or entities, called objects. This distinction demonstrates the ability of the object-oriented database model to handle multiple data formats.

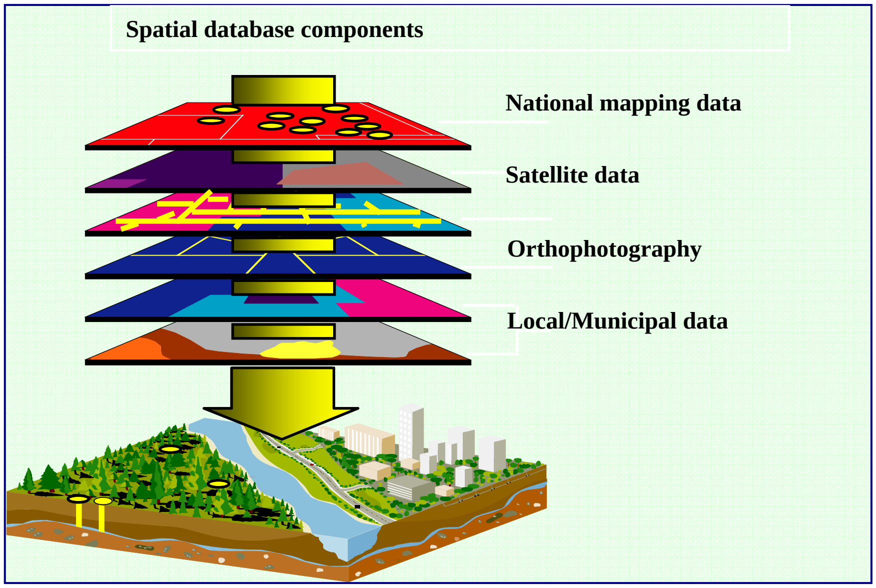

Figure 1: Spatial databases' components as modified from ESRI

The use of relational or other database technologies can result in significant storage overheads and slower processing; to enable compact storage and efficient processing, scientific data is often stored in the form of binary or character flat files. In view of this, there has been recent interest in data visualization; data visualization refers to the capability of visualizing spatial data stored in the spatial database using a particular product. Weng et al. [12] proposed two key approaches for automatically creating data services to support data visualization.

2.5.2.1 Meta-data description language

The first key of Weng's approach is the design of a meta-data description language used for describing a low-level data layout.

2.5.2.2 Automatic generation of efficient data

The second key enables the automatic generation of data setting and access functions for a given meta-data description. One advantage of this approach is that data can be stored in the format it is generated in, avoiding the overhead and effort involved in loading the data in a database system. Another advantage is that managing a new dataset layout or virtual view only involves writing a new meta-data descriptor. This approach was applied successfully to two examples, oil-reservoir management and satellite data processing. These successes show the ability of this tool to handle a variety of different layouts, to scale large datasets and parallel systems and to provide performance comparable to that achieved with hand-written codes.

3 Functionality analysis of major GIS products

GIS functionality can be categorized into four major function groups: mapping, editing, analysis and visualization. This section reviews three GIS products and provides an overview of their usability for application-specific 3D analysis.

Zlatanova et al. [13] discussed the trends in GIS development. The present paper gives emphasis to the three major products widely used by many GIS professionals: Leica Geosystems' ERDAS IMAGINE®, Geomatica® and ESRI® ArcGIS®. The information from Zlatanova et al. [13] and the technical reviews for GIS software products provided by the American Society for Photogrammetry and Remote Sensing (ASPRS) [14] are included.

One basic functionality provided by the three systems studied is the management of different data types, i.e. points, lines, polygons and raster data. The systems also perform and execute spatial operations, including intersection, overlay, distance computation and group analysis. Spatial data types and operations may be a part of different sets of queries. All systems efficiently handle housekeeping operations, the basic functions each GIS product performs. These basic functions include: save, save as, import, export, create project and save project. The housekeeping operations of each software product differ with the type of GIS data and database used; for example, functions used for raster GIS data differ from functions used for vector or elevation GIS data. The system’s basic functions differ with the data format. For example, saving vector layers could be in a specific format such as shapefile, which may not be supported by particular raster GIS products such as Clarke Labs’ IDRISI Software. Housekeeping operations are needed when examining particular GIS functionalities for particular applications. In general, most of the new GIS products, such as ESRI® ArcGIS®, support advanced housekeeping operations for all data sets; moreover, they can integrate and export data in various interchangeable formats. All the GIS products studied support advanced housekeeping functions, including georeferencing, import, export and interchangeable-format saving.

Analysis functionality is the second set of GIS functional requirements. This type of functionality is classified into basic analysis and advanced analysis. The basic analysis operations include data format, geometric and projection transformations, as well as conflation edge-matching and editing. The simple analysis functions also include attribute functions, such as attribute retrieval, classification and verification and can incorporate integrated spatial and attribute simple functions, for example, overlap and classify operations. This type of functionality enables basic editing operations, for example, modifying feature components and adding annotation to features. The last analysis functionality group is the advanced analysis, including 3D-analysis data manipulation, editing and overlay.

For 3D GIS, the TIN is a popular model for representing surface models in GIS, computer graphics and VR because TIN has a simple data structure and can easily be rendered using common graphics hardware. However, while a high-resolution TIN model is needed to represent the details of a model, this high-resolution TIN is very time-consuming because of the large amount of data processed. Yang et al. [15] proposed an approach that dynamically generates multi-resolution TIN models. The iterative edge collapse and split algorithms are basic algorithms used for constructing TIN models. The proposed approach was applied to a study area with a total of 87 152 triangles and 44 003 vertices to evaluate time performance and the quality of the multi-

resolution TIN model generated. The case-study results demonstrate that a reasonable balance between running time and model quality can be achieved.

3.1 ERDAS IMAGINE

ERDAS IMAGINE® is one of the leading GIS and photogrammetry products. ERDAS IMAGINE® can perform all basic and advanced functions as discussed in the previous section. It can manage certain tasks, from determining the exterior orientation over digital elevation model (DEM) extraction to orthorectification, the process of rectifying ortho-images. Similar to the IMAGINE module, the DEM extraction component module of ERDAS IMAGINE® is well-designed and intuitive to use. ERDAS IMAGINE® provides ease of operation for a novice user, while the system provides a lot of flexibility for an advanced user. ERDAS IMAGINE® has low minimum hardware requirements and is a very useful DEM data-production tool. This data can be used as one of the main layers of any GIS, a prerequisite for orthorectification, or as input for generating fly-through in IMAGINE VirtualGIS®. The IMAGINE VirtualGIS® module of ERDAS IMAGINE® provides unique visualization and simulation functions. An example is provided in Figure 2, see Zlatanova et al. [13] .

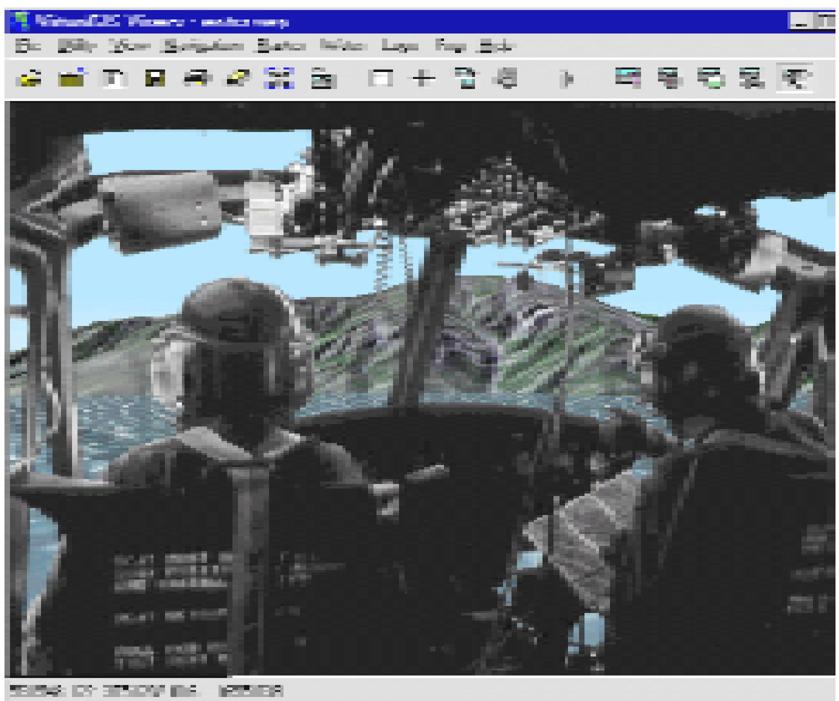

Figure 2: VR model simulated IMAGINE VirtualGIS®, ERDAS®

3.2 Geomatica

PCI Geomatics' Geomatica®, a Canadian product, efficiently generates geometrically-corrected images and mosaics. Geomatica® enables generic database (GDB) creation and geospatial data processing from more formats than any other geomatics software package, avoiding data translation or reformatting. Geomatica® provides a unique interoperable interaction that avoids importing source files from a particular database. The GDB technology allows Geomatica® to directly read, view and process data in exchangeable data formats. Geomatica® supports 100 different data formats, including commercial systems such as ESRI® ArcInfo as well as ESRI® ArcView, ESRI® AutoCAD and Bentley® MicroStation™. It can also integrate emerging raster data standards such as GeoTIFF. It can perform unique data integration and simultaneous processing from multiple databases.

3.3 ESRI ArcGIS

ESRI® ArcGIS®, one of the first commercialized GIS products, has been adopted by many users worldwide. It is a collection of software products running on standard desktop computers or on servers. It is composed of different modules, including ESRI® ArcView, ESRI® ArcEditor and ESRI® ArcInfo. ESRI® ArcView provides extensive mapping, data use and analysis, along with simple editing and geoprocessing capabilities. In addition to the full functionality of ESRI® ArcView, ESRI® ArcEditor includes advanced editing for shapefiles and geo-databases. ESRI® ArcInfo is the full-function, flagship GIS desktop, with all the GIS functions available in any of its basic modules. It extends the functionality of both ESRI® ArcView and ESRI® ArcEditor with advanced geoprocessing. It also includes the legacy applications for ArcInfo Workstation. ESRI® ArcGIS® supports various extensions for particular applications, including ArcGIS® Network Analyst, ArcGIS® 3D Analyst and ArcGIS® Spatial Analyst, and supports various server-based products (see Figure 3).

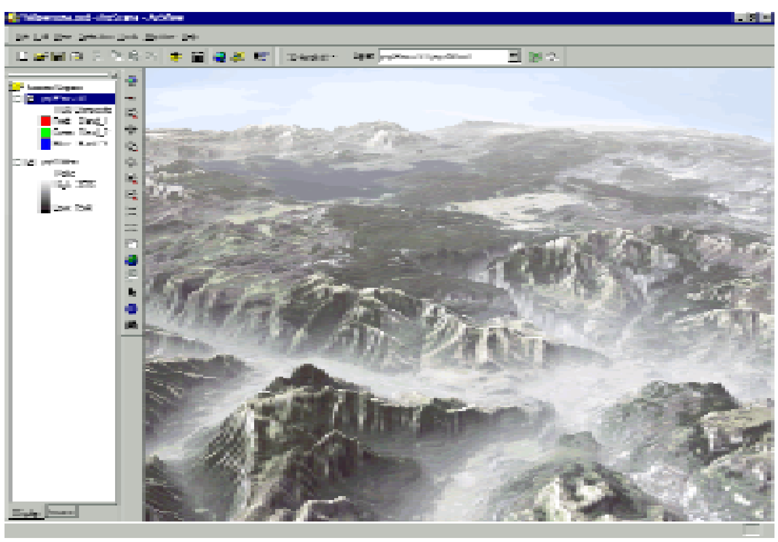

Figure 3: 3D terrain model simulated in ESRI® ArcScene

Table 1 provides comparative analysis of the three studied systems.

Table 1. Comparative analysis of currently available software

SOFTWARE	HARDWARE REQUIREMENTS	VENDOR	APPROXIMATE COST
ERDAS IMAGINE®	Supports most currently-available system configurations	ERDAS, Inc. Atlanta, Georgia www.erdas.com	OrthoBASE: C$5,000 OrthoBASE Pro: C$10,000.00 (includes IMAGINE® OrthoBASE) Advantage: C$4,000.00 Stereo Analyst: C$3,000
Geomatica®	Supports most currently-available system configurations	PCI Geomatics, Richmond Hill, Ontario www.pcigeomatics.com	Geomatica® C$18,000 Smart Digitizer C$3,000
ESRI® ArcGIS®	Supports most currently-available system configurations	Environmental Research Institute, Redlands California www.esri.com	C$9,000
GeoMedia®	Supports most currently-available system configurations	Intergraph, Inc. Madison Al., U.S.A. www.intergraph.com	US$12,000

4 Database system and design requirements

As outlined in Stefanakis and Sellis [16], effective DBMS-repository design for a GIS application requires detailed assessment of both user expectations and the intended repository uses. This section provides an overview and analysis of four major DBMS. These systems were chosen over other systems because they are widely used enterprise editions. Enterprise editions are used by large organizations with large databases and can be linked to a GIS database to provide backend database support. The systems in this report are Oracle® Spatial, Microsoft® SQL Server™, IBM® Informix and ESRI® ArcSDE, all are relational database management system (RDBMS). Common considerations criteria are presented, followed by a review of operational and end-user system design requirements.

Spatial data are usually divided into four categories as in Maguire [17]:

- physical objects: building, road, lake, forest, etc.
- administrative units: private property, province, national park, military area, etc.
- geographic phenomena: temperature, precipitation, accidents, fish distribution, etc.
- derived information: socio-economic, suitability for cultivation, environmental strain, etc.

The major factor that distinguishes spatial data from non-spatial data is the geographic coordinate system. Different constraints and considerations are major factors in the selection of the spatial database systems to be used. The common considerations are:

- database scalability: the possibility of increasing either the database storage capacity or upgrading databases based on the size and capacity of the project; database should be upgradeable to different levels.
- database accessibility: the ease of accessing the database, paging it and querying database attributes
- database availability: the ability to access and query information from the database
- database security: the ability to protect and control access to the database content
- database interoperability: the ability to provide multiple accesses to the database

4.1 Oracle Spatial

Oracle® Spatial is a well known DBMS with a foundation for deploying enterprise-wide spatial information systems. According to Oracle® [18], it enables accurate delivery of location-based services, including spatial-object-type storage, Structured Query Language (SQL) access and spatial operations. Oracle® uses special schemas that prescribe the storage and spatial indexing mechanisms of semantics and supported geometric data types.

4.2 Microsoft SQL Server

Microsoft® [19] describes its SQL Server™ as a next-generation data management and analysis solution, delivering increased security, scalability and availability to an enterprise's data and analytical applications while making them easier to create, deploy and manage. As a DBMS, Microsoft® SQL Server™ provides integrated data management and analysis functionality. Microsoft® SQL Server™ shares data across multiple platforms, applications and devices, making it easier to connect to internal and external systems.

4.3 IBM Informix Dynamic Server

IBM® Informix Dynamic Server is a product of IBM® that provides online data-processing capability. According to IBM® [20], IBM® Informix offers performance, reliability, scalability and manageability for enterprise and workgroup computing. It also provides easy query processing capabilities. In terms of data security, IBM® defines the security system of Informix as a secure, easily-managed system. Informix Dynamic Server's rapid data-deployment integration with other system capabilities provides the benefits of enhanced performance and shortened development cycles.

4.4 ESRI ArcSDE

ESRI® developed ArcSDE in 1995. This DBMS enables fast access to massive datasets, and is accessible by multiple users, as are the other three systems studied. ESRI® ArcSDE is an integrated part of the new versions of ArcGIS®. ArcSDE enables both end users and programmers to access the user-friendly database.

A case study published by ESRI® [1] highlighted the usability of ESRI® ArcSDE as an enterprise DBMS. According to this study, ESRI® ArcSDE was used for storing high-quality, one-foot aerial images and digital-elevation contours of north-central Texas. The combination of the digital-elevation data and aerial photos was used in creating a 3D picture of more than 9,000 square miles. Access to the GIS data created by this project, including more than one terabyte of aerial images, is available to the public via a web service. The case-study system implemented used Microsoft® SQL Server™ as the database for ESRI® ArcSDE, including ESRI® ArcGIS®, and proved to be very efficient. ESRI® ArcGIS® provides a three in one solution that combines DBMS, visualization and analysis.

4.5 System-design requirements

Londsom et al. [21] discussed a new technology known as virtual geospatial information systems (VGIS). Their system design supports real-time VGIS, enabling accurate depiction of terrain elevation, imagery and features such as ground cover, trees, moving vehicles, buildings, other static structures, roads and atmospheric effects. It supports an entire environment composed of multiple parts, i.e., heterogeneous data. This heterogenic integration requires access to multiple databases and real-time rendering. Their system employs real-time, automatic paging and caching techniques. Capabilities of the system enable enhanced visualization. For example, if the system is used to visualize urban scenes, it is likely to manage hundreds to thousands of buildings,

including their textures and street layouts. For flexibility, the terrain visualization sub-system should manage terrain from any part of the world, integrating these terrains into a common coordinate system without seams or gaps (i.e., between LODs or due to multiple coordinate systems).

From the perspective of system-processing capabilities, the most important characteristics are providing timely queries, processing data and managing different data formats from different data sources. The system can handle day and night-time data and environmental factors (rain, snow and lightning); in addition to the other visualization capabilities, another consideration is the system-update capabilities.

4.5.1 User constraints (ADDNS specific)

4.5.1.1 Level of detail

LOD is fundamentally a matter of system visualization capability and data size. LOD techniques are used to simplify both geometry and texture detail. This is necessary to maintain interactive frame rates because the global views typically contain millions, or even billions, of surface polygons, with gigabytes of imagery. Image visualization techniques guarantee meeting an upper limit on the screen space simplification error, an error commonly occurring with large data volumes. The error limits can be manipulated interactively by the user until sufficiently high frame rates are obtained.

With raster data in particular, various systems use different techniques to render large-size databases. Of the four GIS products, ESRI® ArcGIS® is particularly capable of generating image pyramids and assigning various LODs to very large raster files. Geomatica® and ERDAS IMAGINE®, both photogrammetry-oriented products, can manage very large data sizes, assigning image pyramids to any image database to enable fast rendering. GeoMedia® can manage large raster data sizes and render them properly. In general, rendering image databases does not seem to be a problem using today's enormous computing power, and most GIS products in the market can handle image databases efficiently. The key issue with image databases is the need to integrate and visualize different data sources in one database. ESRI® ArcGIS® is very efficient in this function. ESRI's geodatabase concept and its SDE enables very efficient heterogeneous data handling and fast rendering capabilities.

Using real geometric terrain data for visual simulation in 3D space has a significant impact on the GIS-related applications. However, the limitation of available graphic hardware leads to the use of lower-resolution images and less-detailed geometric-terrain data to build a real-time interactive simulation or to display a small area of terrain data. Li et al. [22] proposed a system to conduct visual simulation on large image and geometric data and create a realistic real-time navigation. The system proposes LOD modeling with a quad-tree to speed up the large terrain-mesh rendering and using tiled texture to display the detail of the aerial photographic image in real-time rendering. Real-time navigation of large terrain, with acceptable performance and very high-quality texture image, was achieved. The proposed system has the potential to conduct navigation with even larger geometry and image data. However, the system does not transition smoothly when making the terrain jump from one LOD to another.

4.5.1.2 Data size

Data size is not an issue from the system-capabilities point of view. All of the GIS products discussed can handle large datasets.

Issues related to data size can clearly be seen from the experiment conducted by the U.S. Army Simulation, Training, and Instrumentation Command (STRICOM). The experiment, known as battle command reengineering II (BCRII), used a synthetic environment that employed virtual simulations to depict a large task force executing three basic task-force-level scenarios in realistic combat situations in various experimental configurations. The scenarios were developed to be executed on the Synthetic Theater of War-Europe (STOW-E) terrain database (TDB). There were three objectives for this experiment. One was the further refinement of the battle-command requirements relating to the Battalion Commander, the staff and the digital system capabilities that might be available in 2010. Demonstrating the functional capabilities useful to the Commander and his staff was a further objective. The final objective was to facilitate the cognitive process and decision-making associated with battle command [23]. Issues related to data size in this experiment suggested that the synthetic environment based on the datasets can manage detailed data sets.

4.5.1.3 Hyper-spectral data integration capabilities

Hyper-spectral imaging systems are increasing in importance for a wide variety of commercial and military systems. This increased interest is because a hyper-spectral sensor of a given spatial resolution or pixel size will reveal information on the scene unobtainable by single-band or multi-spectral sensors. There have been several approaches to using a single higher spatial-resolution band to improve the spatial resolution of the hyper-spectral data.

Sutton [24] used night-time satellite imagery provided by the defence meteorological satellite program – operational line scan system (DMSP-OLS). One-kilometre results indicated the usefulness of satellite near infrared data (NIR) for modeling and simulation. In today's applications, advanced processing algorithms using more hyper-spectral data can obtain more accurate results as well as finer data resolution.

4.5.1.4 Integration capabilities

Counsel et al. [25] described the Valhalla project, which integrates GIS-generated Virtual Reality Modeling Language (VRML) with real-time video. The VRML model is used to interpret video images through hyperlinked descriptive information returned as active server pages from the database. The GIS, with information concerning location of objects in the scene, are linked to the objects' information and are used to build the hyperlinked VRML model. This model is connected to the camera-control data, offering a matching field-of-view focus. The VRML model is also used to set up and run a server based on spatial analytical searches to identify and retrieve archived video clips and historic images or photographs on the basis of the objects that are imaged within them. The VRML models used in this project have been evaluated and found particularly useful in enabling an overview of either the current or historic-landscape structure.

4.5.1.5 Insert-tools capabilities

ESRI® products, including ArcGIS®, have the capability to integrate functionality within the MultiGen® creator. The vector-mapping components from the ESRI® ArcObjects library are interchangeable with Creator Terrain Studio™, one of the very popular large-area TDB-generation solutions. ESRI® ArcObjects is the component-based technology framework for ESRI® ArcGIS® software suite. This interoperability enables integrating ESRI® ArcGIS® spatial-database components with Creator Terrain Studio™ by expanding the capability for viewing and editing vector data, all based on ESRI® ArcObjects technology. The enhanced Creator Terrain Studio™ interface allows users to view, edit and create vector data without having to process this data in another software application, saving significant time and resources.

4.5.1.6 Employability and integration

Cornish et al. [26] developed and applied a data-fusion process to the southwest Asia TDB, to provide a DEM model representing terrestrial and ocean regions. DEM generates features for integrating high- and low-tide marks, streams with river banks and water surfaces, cut-and-fill roads and obstacles into the 3D terrain surface. The southwest Asia TDB was originally developed for the STOW Advanced Concept Technology Demonstration (ACTD) and is one of the largest and most complex TDBs for the synthetic natural environment (SNE) built to date. This application provides an example of how vector, imagery and DEM source data can be converted, merged and assimilated into a single, coherent and unified data model for representing the SNE. It demonstrates the capability and flexibility of GIS technology to assimilate and synthesize data from multiple sources and resolve conflicts arising from using multiple-source data at different resolutions and of differing data quality.

Damron and Daniel [27] processed the STAR-3i data to produce DEMs and magnitude images in tiles in digital format. The DEMs were produced as elevation values on a regular 10-meter-grid interval in Northing and Eastings. The data set extends north of Sacramento, south to Fresno, following the Sacramento and San Joaquin Rivers, with an area coverage of about 22 000 km^2.

Theodore [28] discussed the role of GIS and RS in response to the southern California wildfire in 2003. RS and GIS technology played a key role in pre-planning, emergency response during the fire and post-event recovery. In the pre-planning phase, aerial photos and satellite imagery assessed drought and determined the potential forest-fire area locations. During the fire, satellite data accurately located wildfire heat sources. This helped incident managers develop their strategy during the initial phases of the fire, when good perimeter of event location may have been lacking. In the post-fire phase, GIS identified the areas that burned more than others, contributed to dead-tree removal plans and reduced future wildfire risks through improved forestry management.

4.5.1.7 Texture-data incorporation capabilities

Raubal and Kuhn [29] discussed the importance of evaluating the decision-making usability and data-source utility to determine service feasibility. The authors proposed doing this by simulating, with the ontologies, the tasks to be supported by the service. From an information-systems and artificial-intelligence perspective, ontologies are content theories identifying specific classes of

objects and relations that exist in some domains. Such a simulation needs to access data about entities, based on the actions they generate and the events they participate in. This requires that ontologies include information about these activities and events. The method was demonstrated through a real-world scenario of navigational instructions for crossing a river by car.

4.5.1.8 Environmental-data integration capabilities

Denby and Schofield [30] discussed the roles of advanced computer techniques, including GIS, computer graphics (CG) and VR, in accurate visualization. GIS collect, store and analyse the extensive environmental data describing groundwater flow, contamination range and environmental consequences, evaluating remedial measures. Many mining-related challenges have been resolved by the U.S. geological surveys applying GIS, including map making, natural-resources site selection, emergency-response planning and site assessment. GIS technology also depicted the terrain of a certain area before and after mining. By examining historic images over a 40-year period, this application calculated mining impacts, resolving a legal case. The authors predicted that GIS would greatly improve mine management, maintaining economic vitality and environmental quality. VR applications in mining include environmental visualization, safety-awareness training systems, accident reconstruction, data visualization, ergonomic design, simulation systems, driving simulators, training systems and hazard-awareness systems.

4.5.2 Operational constraints

4.5.2.1 Estimated person-hours

Estimated person-hours using GIS varies with the software and with the level of user knowledge. It is difficult to estimate a particular time limit for performing a particular task. In general, GIS is a tool that can be used for solving a variety of problems, but depending on the user's needs, its task-oriented learning curves are unpredictable. Most software licenses include ample details and manuals, greatly simplifying the job for a novice user. Some software packages come with training-course offers to provide the basic competency level required for a particular task.

4.5.2.2 Data maintenance and updates

GIS data are sometimes complicated. Data can be found in multiple formats, scales and coordinate systems, complicating GIS data maintenance. A strict quality-control (QC) protocol is required to ensure the quality and fast processing of GIS data-maintenance operations. A standardized data format, coverage and coordinate system are required for efficient data-maintenance operations. Issues such as scale, accuracy and quality of data should be clearly addressed in the geospatial-database QC policy. When new datasets arrive, basic housekeeping processes are required to ensure that the standards of the received data are consistent with, and comparable to, the available spatial-data content. Almost all software package data formats are now interchangeable and are capable of integrating various spatial formats. In terms of data-processing capabilities, most GIS software packages are capable of storing various spatial-data structures. All GIS projects require a clear definition of spatial-database requirements and how they help achieve the project's objectives.

5 Applications review

The trend for spatial database systems and GIS is toward a non-centralized approach. Currently many synthetic environments' creators are using semantic, systems and data interoperability. The U.S. Army is using distributed systems because distributed systems share data and system load over many subsystems. They enable rapid display of information from many perspectives. This section provides a broad overview of various applications of geospatial information technologies for a wide range of applications. Special emphasis is given to defence-related applications.

5.1 Distributed Interactive Fire Mission II

The Distributed Interactive Fire Mission II (DIFMII) was an experiment conducted by the U.S. Army STRICOM. The DIFM concept ultimately optimized shooter survival by:

- developing integrated, multi-agent (distributed) automated fire-control systems capable of accepting target information from multiple sources
- determining available firing platforms (based on location, activity and obstacle avoidance)
- tasking unencumbered shooters
- passing fire-solution data to assigned platforms
- displaying shooter target-acquisition indicators to facilitate search and rapid engagement procedures

The experiment used a synthetic environment employing virtual simulations to depict an armour platoon executing six platoon-level scenarios in realistic combat situations in various experimental configurations. The scenarios were executed on the STOW-E TDB using movement-to-contact vignettes. One objective of the experiment was determining the operational effectiveness of an armour-platoon-equipped alternative DIFM application during threat engagements. Other objectives included identifying software requirements essential to DIFM alternatives at platoon-level operations and serving as a foundation for subsequent evaluation of DIFM growth to support battalion level [31]. Most modern GIS are based on a file system, therefore each GIS has its own logical data formats and file structures. These file-system-based GIS have several well-known problems in the database area: data sharing, redundancy and inconsistency, transaction control and recovery, as well as concurrency control and security.

5.2 Relational database model

Many approaches are applied to address the GIS problems encountered; one feasible approach, using well-established database models is known as the relational database model. Zhao et al. [32] proposed a generic relational-database schema that accommodates various types of GIS data and complies with the OpenGIS® simple features specification for SQL developed by the OpenGIS® Consortium (OGC). This proposal can be used for any geographic application with geographic objects represented by 2D geometry with linear interpolation between vertices. The generic schema would automatically generate a relational database schema for any existing or

new 2D GIS dataset, facilitating the migration and deployment of GIS data in well-established relational database environments, similar to the basic relational databases supported by ACESS. Consequently, sharing and integrating GIS data becomes more feasible. In addition, because any RDBMS can be used, this facilitates developing a GIS application system on existing GIS data. The proposed schema and automatic schema-generation mechanism were verified by developing and testing relational GIS.

5.3 Data fusion

Hong et al. [33] established a common technology-demonstration environment using the same hardware infrastructure to develop, evaluate and demonstrate all data-fusion techniques and capabilities. The objective of this effort was to ensure that data-fusion developments aimed at different programs could leverage previously-developed capabilities. Since 1999 Defence Research Development Canada (DRDC) has been developing data-fusion capabilities in support of Canada's defence programs through collaboration with Lockheed Martin (LM) Canada. The initial capability fused the above water warfare (AWW) onboard-sensor data of the Halifax-Class frigate. Then, image-fusion capabilities were added to provide data-fusion capability for airborne surveillance. The blackboard-based architecture was chosen to support the rules-based, concurrent and ad hoc reasoning requirements of higher-level fusion. Data-fusion methods, techniques and capabilities are being developed and integrated into the technology demonstrator (TD) based on the priorities of the various programs involving LM Canada. This research has developed an overall data-fusion model, foreseeing the evolution into the human-in-the-loop, multi-platform data fusion of levels 1 through 4 and supporting Network Centric Warfare (NCW). Currently, Multi-Platform Multi-Source Data Fusion (MP MSDF) – Level 1 collaborative data fusion capabilities have been demonstrated. The TD also contains a subset Situation and Threat Assessment and Resource Management (STA/RM) capability – Level 2, 3 fusion and RM decision support functionality, which is available on any platform. However, this provides decision support for the platform alone; MP STA/RM capabilities are not yet developed. Currently the TD's MP MSDF includes bearing-only association, track-to-track fusion, backward-compatible data integration, bearing intersect fix management, etc., in an architecture permitting data exchange between collaborating platforms. Work is on-going to mature the MP MSDF, offering more sophisticated fusion techniques, incrementally adding capabilities, evolving Levels 2, 3 fusion and RM and to introduce Level 4 fusion – specifically fusion management, i.e., an adaptive fusion capability.

Kupier and Smits [34] discussed the development of a terrain for Bosnia; this terrain was developed for an advanced simulation purpose, with the support of the U.S. Army STRICOM. The developed terrain will be used in conjunction with the electronic battlefield facility (EBF) simulators, with visual systems also based on Performer 2.1 and running on Silicon Graphics, Inc® (SGI) workstations. We are working on the following simulators: the Leopard 2A5 tank, and the Fennek reconnaissance vehicle. The developed terrain is a very appropriate, synthetic-environment TDB.

5.4 Thin client

Morrison and Purves [35] developed a web-based approach to deliver landscape visualization (in both 2D and 3D), suitable for thin-client users. The thin-client approach maximizes the final

visualization service accessibility for non-geospatially-aware users. This design provides thin-client users with more control over the mode of visualization, eliminating the sophisticated thick-client tools. Thick-client tools require extensive GIS training investment in both time and money. The tools are customized on the server side. This landscape visualization tool conforms to OpenGIS® web-map server specification, enabling future integration with other map data. The approach was successfully applied to two case studies. In these cases, a lecturer and a teacher, who were not GIS aware, were able to rapidly generate suitable visualizations to illustrate simple points without assistance.

5.5 Web-based client

Bo [36] proposed a web-based dynamic and interactive environmental visualization approach that enables the simulation of a real-time environmental process. Current internet GIS products offer static-map display. The visualization model aims to overcome the limitations of static-map display by visualizing a dynamic environmental-modeling process in a continuous form. In the traditional mode, data analysis and visualization are performed as a post-processing step after a simulation has been run. This delays the detection of errors to the post-processing step. The dynamic-interactive approach provides an efficient tool for scientists to interpret and interact with the data as computations proceed. The approach was applied using the topographic model (TOPMODEL), a rainfall run-off model, to examine the approach's feasibility. The approach was able to provide the user with dynamic interactive 3D visualization results.

Aydin et al. [37] discussed the process of building a traditional spatial database in detail. The first step was building the operational base layers by scanning, digitizing, vectorizing and georeferencing all hard-copy network-plan maps and drawings to Universal Transverse Mercator (UTM) using a Gauss-Kruger projection. The next step was to develop a database for storing alphanumeric information about buildings and other features of interest. Next the database-accuracy verification stage required adopting a quality-assurance (QA) program. Orthophotos and photogrammetric maps were also used to resolve any map inconsistencies and determine misplaced-facilities locations.

6 Conclusions and recommendations

GIS technology is being adopted by more users every day and is being used by many organizations and sectors. GIS data formats are no longer an issue for the large GIS user community. Most of the currently available GIS software has the capability of interchanging different data formats and using the data for particular applications. The development of GIS data models is still a matter of research and development. When the object-class data model was developed many of the crucial modeling questions were answered. The object-class data model is efficient in integrating various data structures.

The task of designing spatial databases is evolving daily. In the early days of GIS, analysts digitized many data sets before starting their actual work. Many jobs as digitizer are no longer available in the GIS industry; however, many users still need to do occasional, limited digitization work for a particular purpose. The automated feature extraction from satellite imagery is rapidly evolving; this will certainly lead to some automation in spatial-database building. An additional factor expediting the rapid process of spatial-database building is the availability of data. Many private- and public-sector data vendors are currently sharing their data libraries with others. An example of this is the Canadian portal, Geogratis (http://geogratis.cgdi.gc.ca/), where many data sets are shared. The key considerations are the validity of data in terms of its quality, date of production and accuracy. In a rapidly-changing world, data validity is an issue because of accuracy and representation issues. Many data sets are no longer valid because of new urban developments or new road diversions; this presents a clear challenge for spatial-database designers to keep up with new data versions. Another important issue is the precision of data, in terms of the level degree of real-world abstraction. All GIS products enable snapping and georeferencing However, there is a clear need for strict, industry-acceptable, data-accuracy standards for simulation spatial databases.

Most GIS software provides similar functionality within the analysis, editing and visualization domains. However, the key distinction is the capability of the software to provide stable performance, fast data processing and management and wide interchangeable data-sharing capabilities. From this perspective, most GIS products focus on either advanced vector or raster functionality. Raster-oriented products always provide additional photogrammetric functionality. Based on that, ESRI® ArcGIS® provides stable, advanced functionality and quick processing of data. Geomatica® provides advanced image- and photogrammetric-processing capabilities. From a database perspective, ESRI® ArcSDE is unique and has the capability of connecting to many other databases, including Microsoft® SQL Server™ and Oracle® Spatial.

In terms of application development, all the evaluated GIS-based technologies are capable of providing advanced system development. Many applications are being developed in many fields; the only considerations are the user needs and the application requirements. With ever-advancing computing capabilities, system hardware requirements are no longer an issue.

ESRI® ArcGIS® with ESRI® ArcSDE can provide efficient capabilities in dealing with small and medium spatial databases, while integration with Oracle® Spatial can deal with very large databases. Geomatica® is appropriate in dealing with photogrammetry functions and aspects related to spatial databases; it also has the capability of accessing different databases and providing on-the-fly data conversion.

We recommend adopting geospatial-information data standards. Data standards are very helpful in defining the data to purchase for particular applications. Identifying a clear protocol that controls frequent and timely updates of data is also recommended. Standard data-set QC procedures are required to combat data errors, coordinate systems, offer georeferencing and address other issues related to the basic data pre-processing.

We recommend organizing training sessions for personnel involved with spatial databases. GIS and spatial databases tools are used by many professionals in different fields. Basic use of GIS and spatial databases can be learned in a reasonable time.

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Annex A Spatial database design process

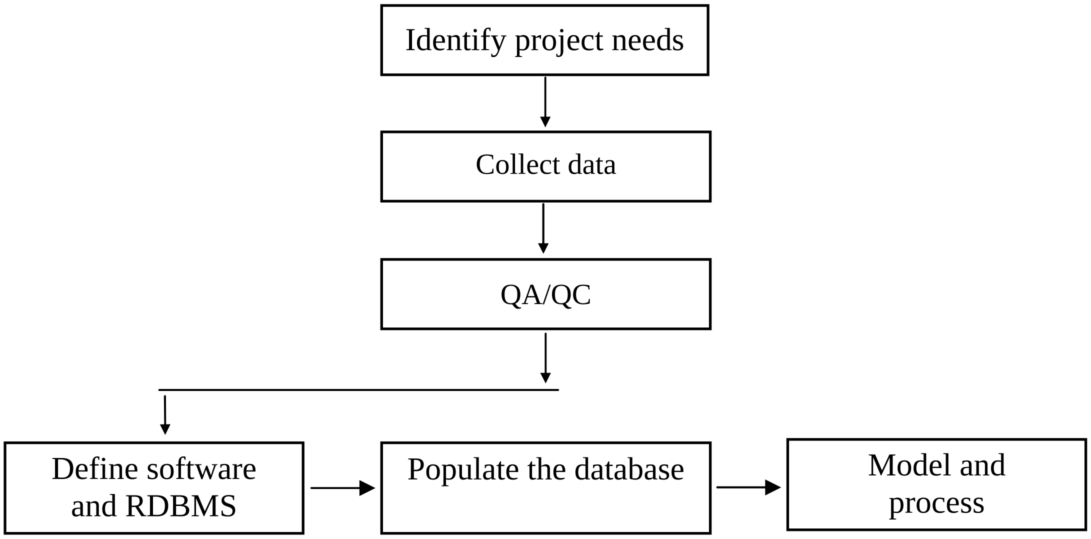

Figure 4: Spatial database design process: requirements analysis

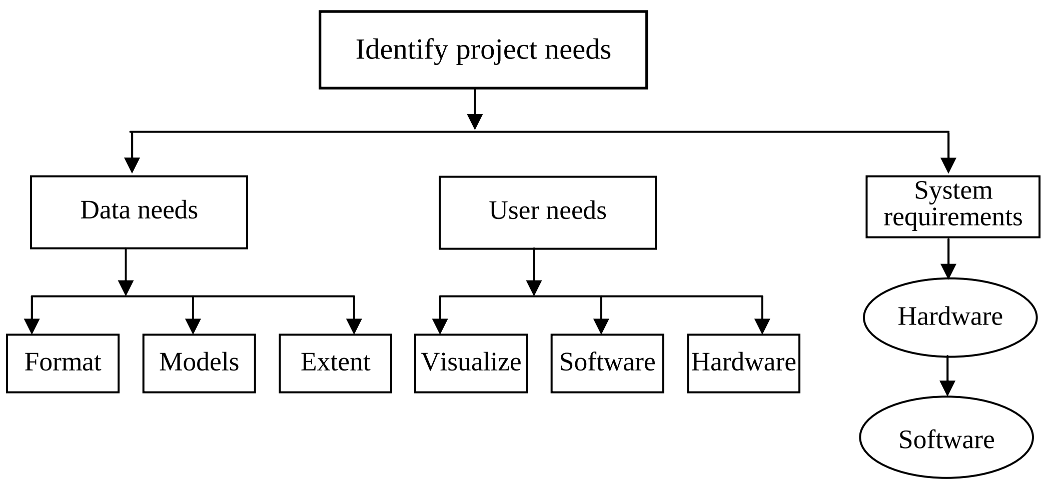

Figure 5: Spatial database design process: needs identification

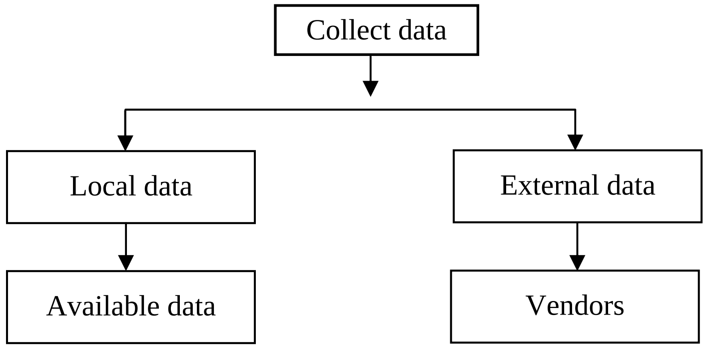

Figure 6: Spatial database design process: data collection

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List of symbols/abbreviations/acronyms/initialisms

ACRONYM / SYMBOL	*DEFINITION*
2D	two dimensional
3D	three dimensional
ADDNS	Advanced Deployable Day And Night Simulation
ACTD	Advanced Concept Technology Demonstration
API	application program interface
ARC INFO	GIS software produced by Environmental research Institute ESRI
ASPRS	American Society for Photogrammetry and Remote Sensing
AWW	above water warfare
BCRII	battle command reengineering II
CG	computer graphics
DBMS	database management systems
DEM	digital elevation model
DIFMII	Distributed Interactive Fire Mission II
DMSP-OLS	defence meteorological satellite program - operational linescan system
DND	Department of National Defence
DOD	Department of Defense
DRDC	Defence Research and Development Canada
DTIC	Defense Technical Information Center
EBF	electronic battlefield facility
GDB	generic database
GIS	geospatial information systems
GPS	global positioning system
IDRISI	Raster-based GIS software, produced by Clarks University, MD, USA.
IT	information technology
LM	Lockheed Martin
LOD	level of detail
MP MSDF	Multi-Platform Multi-Source Data Fusion
MRC	Medical Research Council
NCW	Network Centric Warfare
NIR	near infra red
NSERC	National Sciences and Engineering Research Council
OGC	OpenGIS® Consortium
QA	quality assurance
QC	quality control
RDBMS	relational database management systems

RM	resource management
RS	remote sensing
SDE	spatial database engine
SGI	Silicon Graphics® Inc
SNE	synthetic natural environment
SQL	Structured Query Language
SSHRC	Social Sciences and Humanities Research Council
STA/RM	Situation And Threat Assessment And Resource Management
STOW-E	Synthetic Theatre Of War-Europe (STOW-E)
STRICOM	Simulation, Training And Instrumentation Command
TD	technology demonstrator
TDB	terrain database
TIN	triangular irregular network
TOPMODEL	topographic model
UTM	Universal Transverse Mercator
VGIS	virtual geographic information systems
VRML	Virtual Reality Modeling Language
VR	virtual reality

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Geospatial information systems (GIS) are a relatively new technology. The key GIS technology strengths are its capabilities to store attributes of various spatial features, provide spatial-analysis functionality and offer multiple-perspective, two-dimensional (2D) and three-dimensional (3D) visualizations. This report presents an overview of the basic concepts of GIS and spatial databases, provides an analytical usability evaluation and critically analyses different spatial-database applications for different fields, with special emphasis on defence-related applications. We provide a comprehensive spatial-database evaluation methodology. Basic and advanced functions for GIS operations are analysed, with a focus on selected major GIS products and selected common database systems. Optimal system-requirement recommendations for spatial-database design are provided, with particular attention paid to the needs of the Advanced Deployable Day and Night Simulation (ADDNS) project. This report provides a detailed overview of spatial-database technologies to assist decision-makers with selecting the best system for a particular task.

Les systèmes d'information géographique (SIG) constituent une technologie relativement nouvelle. Les atouts technologiques des SIG sont leur capacité à stocker des attributs de diverses entités spatiales, leurs fonctionnalités d'analyse spatiale et leurs multiples possibilités de visualisation en perspective, en deux dimensions (2D) et en trois dimensions (3D). Ce rapport présente un aperçu des concepts fondamentaux des SIG et des bases de données spatiales tout en offrant une évaluation de leur utilité pour l'analyse; on y présente en outre des analyses critiques de différentes applications des bases de données spatiales dans différents domaines en insistant en particulier sur les applications reliées à la défense. Nous offrons une méthodologie complète d'évaluation des bases de données spatiales. Les fonctions de base et évoluées des SIG sont analysées d'après les principaux produits de SIG et des systèmes communs choisis de bases de données. Des recommandations sont formulées quant aux exigences systèmes optimales pour la conception de bases de données en prêtant une attention particulière aux exigences du projet de la simulation déployable avancée pour la vision de jour et de nuit (ADDNS). Le présent rapport fournit un aperçu détaillé des technologies des bases de données spatiales comme aides à la prise de décisions pour le choix du système le mieux adapté à une tâche particulière.

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Spatial; database; usability; ADDNS